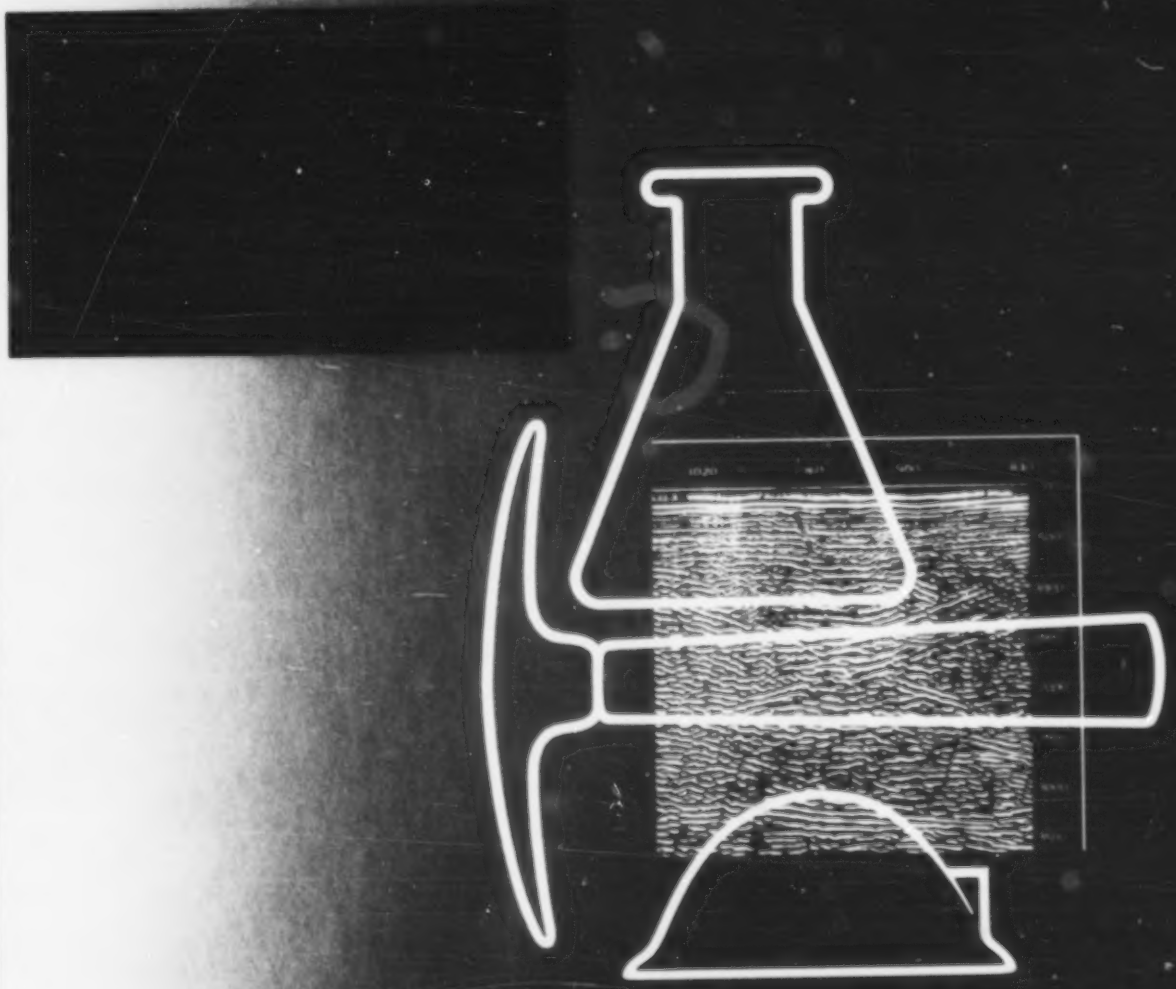
COOPERATION

COOPERATION AGREEMENT ON MINERAL DEVELOPMENT

ENTENTE DE COOPÉRATION SUR L'EXPLOITATION MINÉRAL



Canada

New Brunswick Nouveau Brunswick

New Nouveau
Brunswick

Natural Resources and Energy
Mineral Resources

Open File Report 91-17

FINAL PROJECT REPORT FOR MISP PROJECT: CHARACTERIZING AND CLEANING OF ZINC CONCENTRATES

G.S. Dobby and D.I. Castillo

Department of Metallurgy and Material Sciences
University of Toronto
Toronto, Ontario M5S 1A4

ISSN 1183-5508

Price $2.00

92-01826/

Open File Report 91-17

Final Project Report for MISP Project: Characterizing and Cleaning of Zinc Concentrates

This report should be referenced in the following manner:

DOBBY, G.S., and CASTILLO, D.I. 1991. Final project report for MISP project: Characterizing and cleaning of zinc concentrates. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 91-17, 29 p.

This report has been prepared for:

Mineral Resources
Department of Natural Resources and Energy
Province of New Brunswick

Hon. Alan R. Graham
Minister of Natural Resources and Energy

Hon. Doug Tyler
Minister of State for Mines and Energy

December, 1991

Final Project Report for MISP Project

CHARACTERIZING AND CLEANING OF ZINC CONCENTRATES

by

G. S. Dobby and D. I. Castillo
Department of Metallurgy and Materials Science
University of Toronto
Toronto, Ontario M5S 1A4

April 1, 1989

ABSTRACT

During the past 20 months an analysis of the zinc cleaning circuit at Brunswick Mining and Smelting has been made. The project consisted of two parts. Part I was an evaluation of the causes of variability in zinc concentrate quality, using a set of six composite samples prepared from daily samples for L1/L2 circuit over a period between October 1986 and May 1987. The rationale for this work came from the highly scattered performance on a daily basis, as recorded by zinc grade-recovery. The six composites, having performances ranging from 'poor' to 'average' to 'good', were characterized for: element and mineral grades and recoveries, size distribution, pyrrhotite content, and Zn:Fe ratio of sphalerite (by SEM).

The conclusion from the work in Part I is that the scatter in the zinc grade-recovery was a result of:

(i) varying zinc circuit feed grade (composite 2 has better performance for this reason), and

(ii) varying grind (composites 5 and 6 have poor performance for this reason).

Lead assay and Zn:Fe ratio of sphalerite did not vary significantly between the six composites. A troubling aspect of the work was the large difference between assays obtained from (i) the average of daily values used to prepare the composite, and (ii) the assay on the composite itself.

Part II of the project was an evaluation of the relative contributions toward pyrite recovery of three mechanisms: entrainment, flotation, and incomplete pyrite-sphalerite liberation. This was accomplished through a unique approach which included conducting pilot flotation column tests on-site using zinc 2nd cleaner feed. Plant 2nd cleaner performance was compared with the column performance to measure the degree of hydraulic entrainment occurring in the plant cells. The column concentrate was then evaluated for pyrite liberation; since entrainment of pyrite into the column concentrate is considered to be zero, any liberated pyrite in the column concentrate is present as a result of flotation.

The conclusions from the work in Part II are:

(i) entrainment accounts for 20 to 40% of the pyrite recovery in the 2nd zinc cleaning stage (depending on the total zinc recovery in the stage, a lower proportion of the pyrite recovery being caused by entrainment at the higher levels of Zn recovery), and

(ii) for the balance of the pyrite recovered in the 2nd cleaning stage a significant proportion (about 40 to 50%) is accounted for by flotation (mechanism (b)).

RÉSUMÉ

Au cours des 20 derniers mois, une analyse des circuits de nettoyage du zinc à la Brunswick Mining and Smelting a été effectuée. Le projet comprenait deux parties. La première partie fut une évaluation des causes de la variabilité dans la qualité du concentré de zinc, par l'utilisation d'une série de six échantillons composites préparés à partir d'échantillons quotidiens pour le circuit L1/L2 couvrant une période allant d'octobre 1986 à mai 1987. La raison de ce travail provenait du bilan métallurgique quotidien très variable tel qu'enregistré sur les courbes récupération-teneur pour le zinc. Les six composites, ayant des bilans variant de pauvres à moyens, furent caractérisés en fonction de : la récupération et la teneur en éléments et en minéraux, la granulométrie, le contenu en pyrrhotine et le rapport Zn:Fe da la sphalérite.

La conclusion de la première partie de l'étude est que la dispersion observée sur les courbes récupération-teneur était le produit :

i) de la teneur d'alimentation variable dans le circuit du zinc (c'est pourquoi la séparation du composite n° 2 était relativement bonne),

ii) du broyage à finesse variable (c'est pourquoi la séparation des composites 5 et 6 était mauvaise).

L'analyse pour le plomb et le rapport Zn:Fe pour la sphalérite n'ont pas varié de façon significative parmi les six composites. Un aspect troublant de l'étude a été la grande différence entre les analyses obtenues à partir de : (i) la moyenne des valeurs quotidiennes utilisées pour préparer le composite, et (ii) l'analyse du composite lui-même.

La deuxième partie du projet fut une évaluation des contributions relatives des trois mécanismes pour la récupération de la pyrite : l'entraînement, la flottation et la libération incomplète de la pyrite-sphalérite. Pour ce faire, nous avons utilisé une approche inhabituelle en traitant sur place des échantillons d'alimentation des deuxièmes nettoyeuses de zinc avec une colonne de flottation pilote (ceci afin de déterminer l'importance de l'entraînement hydraulique dans les deuxièmes nettoyeuses). Le degré de libération de la pyrite dans les concentrés de la colonne fut alors évalué; puisque l'entraînement de la pyrite dans la colonne est considéré comme étant égal à zéro, toute pyrite libérée de ce concentré s'y retrouve par flottation vraie.

Les conclusions du travail de la deuxième partie sont :

i) l'entraînement contribue de 20 à 40 % de la récupération de la pyrite dans les deuxièmes nettoyeuses du zinc (plus la teneur en zinc augmente, plus la contribution de l'entraînement à la récupération totale de pyrite diminue), et

ii) pour le reste de la pyrite récupérée au deuxième nettoyage, une proportion importante (environ 40 à 50 %) s'explique par flottation vraie (le deuxième des trois mécanismes).

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the help and support provided to this project by the mineral engineering staff at Brunswick Mining and Smelting, especially Len Surges, Claude Bazin and Sheila Ounpuu. Funding was provided by the New Brunswick Mineral Investment Stimulation Program (MISP) and Brunswick Mining and Smelting.

TABLE OF CONTENTS

PAGE

Abstract

Acknowledgements 1

List of Figures and Tables 3

1. Part I - Evaluating the causes of variability in zinc concentrate quality 4

1.1 Circuit performance summary, October 1986 to May 1987 4

1.2 Selection of composite samples 8

1.3 Assays on zinc concentrate composites 8

1.4 Analysis and examination of composites 11
- 1.4.1 Lead assay of zinc circuit feed
- 1.4.2 Zinc assay of zinc circuit feed
- 1.4.3 Pyrrhotite content of zinc concentrate
- 1.4.4 Zn:Fe ratio of sphalerite
- 1.4.5 Size distribution of zinc circuit feed

1.5 Conclusions and recommendations regarding the causes of variability in zinc concentrate quality 15

2. Part II - Evaluating the relative contributions toward pyrite recovery in the zinc circuit 16

2.1 Column flotation of zinc circuit feed 16
- 2.1.1 Assessment of pyrite recovery by entrainment
- 2.1.2 Assessment of pyrite recovery by flotation and incomplete liberation

2.3 Conclusions and recommendations regarding the contributions toward pyrite recovery in the zinc circuit 21

Appendix tables 22

LIST OF FIGURES

		PAGE
Figure 1	Grade-recovery plot for daily results October 1986 to May 1987	6
Figure 2	Zinc grade-recovery plots: a) feed grade < 9.0% Zn b) feed grade > 9.0% Zn	7
Figure 3a	Zinc grade-recovery for the six composites using the average of the daily assays	9
Figure 3b	Zinc grade-recovery for the six composites using the actual assay of the composite samples	9
Figure 4	Zinc circuit separation efficiency versus zinc content of zinc circuit feed	12
Figure 5	Zinc circuit separation efficiency versus particle size (% +400 mesh) of zinc circuit feed	14
Figure 6	Pyrite recovery versus sphalerite recovery for the 2nd zinc cleaner, obtained from both column flotation tests and plant surveys	17

LIST OF TABLES

Table 1	Summary of zinc circuit performance assessment (L1/L2) October 1, 1986 to May 31, 1987	5
Table 2	Summary of composite samples for daily results October 1986 to May 1987	6
Table 3	Performance summary of composites based on actual assays of the composite samples	10
Table 4	Zinc assays of concentrates from the six composites	10
Table 5	Pb circuit performance of composite samples	12
Table 6	SEM analysis for Zn:Fe ratio of sphalerite in composite samples	13
Table 7	Particle size distribution of zinc circuit feed	14
Table 8	Flotation column and plant survey results on zinc 2nd cleaner	17
Table 9	Summary of liberation analysis on column and plant concentrates	20
Table A1	Make up of composite samples	22
Table A2	Details of circuit performance for each composite	23
Table A3	Size-by-size results of plant and column testing	26
Table A4	Size-by-size recoveries for plant and column tests	29

1. PART I - EVALUATING THE CAUSES OF VARIABILITY IN ZINC CONCENTRATE QUALITY

1.1 CIRCUIT PERFORMANCE SUMMARY, OCTOBER 1986 to MAY 1987

The first phase of this project was the assessment of BMS zinc circuit performance over a period of several months, with the objective of identifying the causes of variable circuit performance. To initiate this phase of the work daily metallurgical results were studied using data from October 1, 1986 to May 31, 1987.

A summary of the plant performance for line L1/L2 during this period is given in Table 1. Feed assay was 9.0% Zn with a standard deviation of 0.7% Zn and a relative standard deviation (V) of 7.8%; concentrate assay was 50.6% Zn with V - 2.2%; zinc recovery to concentrate from mill feed was 74.2% with V - 4.2% (zinc concentrate grade from line 3 was 50.6% Zn with V - 2.8%). A Zn grade-recovery plot for all the data is shown in Figure 1. Clearly, no grade-recovery relationship is evident. As well, time plots that were prepared showed no extended periods of either high or low grade/recovery.

To assess the effect of feed Zn assay upon Zn circuit performance, the data was split into two groups; one consisting of daily feed assays less than the average feed grade (9.0% Zn) and the other with feed assays greater than 9.0% Zn. The results of this data summary are also given in Table 1. The average feed grades of the two groups were 8.4 and 9.6% Zn, concentrate grades were virtually the same (50.5 and 50.7% Zn), and recovery to zinc concentrate was 73.8% for the lower grade group and 74.9% for the higher grade group. Thus, on average, a 12.5% reduction in feed assay (9.6 to 8.4%) yields a 0.4 relative percentage reduction in concentrate grade and a 1.5 relative percentage reduction in Zn recovery. These results show that circuit performance on average was only slightly dependent upon feed zinc content and suggests that the scatter in the grade-recovery plot of Figure 1 is not due to feed assay variability. (See also Figure 2, the grade-recovery graphs for the two groups.) A statistical analysis of the parameter [Zn recovery/feed grade] has confirmed the weak dependence of circuit performance upon feed grade (over the range considered).

Finally, consider the relative variabilities of concentrate grade and Zn recovery. From Table 1 it can be seen that the relative standard deviation of Zn recovery is about twice the relative standard deviation of concentrate grade. This is likey a reflection of circuit control strategy.

Table 1 Summary of Zinc Circuit Performance Assessment (L1/L2)
October 1, 1986 to May 31, 1987

VARIABLE	MEAN VALUE	STANDARD DEVIATION	RELATIVE STND. DEV. (%)	MINIMUM VALUE	MAXIMUM VALUE
(a) All data (239 daily assays)					
Feed % Zn	9.0	0.7	7.8	6.7	10.8
Conc % Zn	50.6	1.1	2.2	46.3	52.8
Zn rec'y from mill feed	74.2	2.9	3.9	60.5	81.9
Zn rec' from Zn cct. feed	83.0	3.5	4.2	65.9	90.9
(b) All days with feed grade < 9.0% Zn (121 daily assays)					
Feed % Zn	8.4	0.4	4.8	6.7	9.0
Conc % Zn	50.5	1.1	2.2	46.3	52.7
Zn rec'y from mill feed	73.8	3.0	4.1	60.9	80.8
(c) All days with feed grade > 9.0% Zn (117 daily assays)					
Feed % Zn	9.6	0.4	4.2	9.0	10.8
Conc % Zn	50.7	1.2	2.4	46.5	52.8
Zn rec'y from mill feed	74.9	3.2	4.3	60.5	81.9

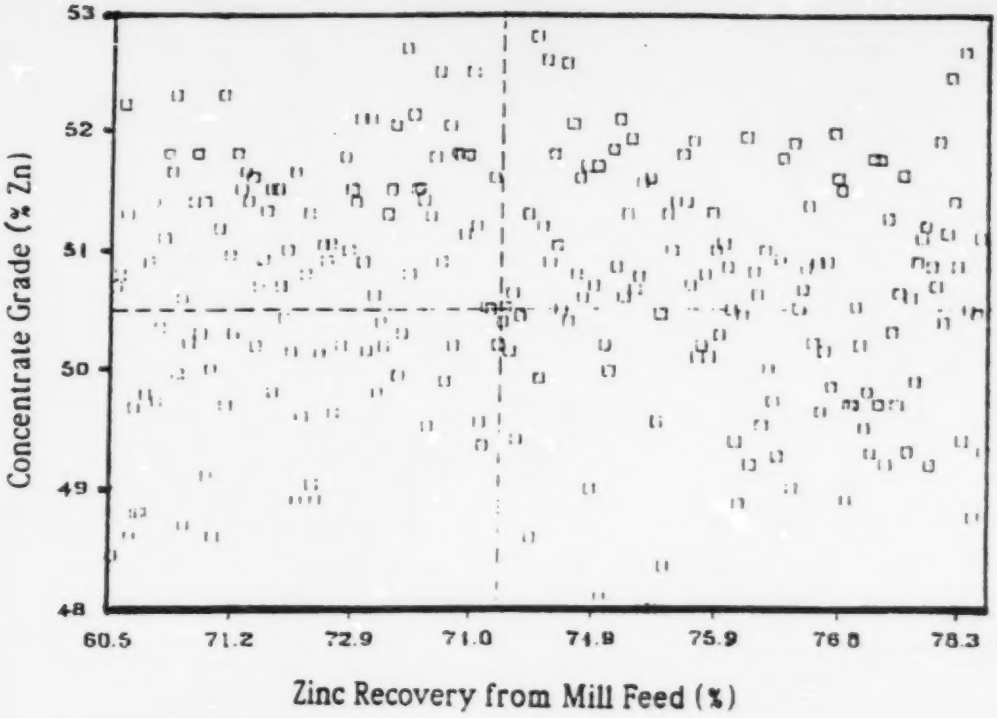


Figure 1 Grade-recovery plot for daily results October 1986 to May 1987

Table 2 Summary of Composite Samples(based on average of daily assays)

COMPOSITE NUMBER	COMPOSITE DESCRIPTION	# OF DAYS IN COMP.	FEED GRADE (% Zn)	CONC. GRADE (% Zn)	ZINC RECOVERY (%)
1	mid grade mid recovery	7	9.1	50.5	74.1
2	high grade mid recovery	5	9.4	50.6	74.0
3	high grade low recovery	7	9.2	51.6	71.7
4	high grade high recovery	7	9.2	51.8	76.8
5	low grade low recovery	3	8.6	49.0	72.0
6	low grade high recovery	5	8.8	49.4	76.2

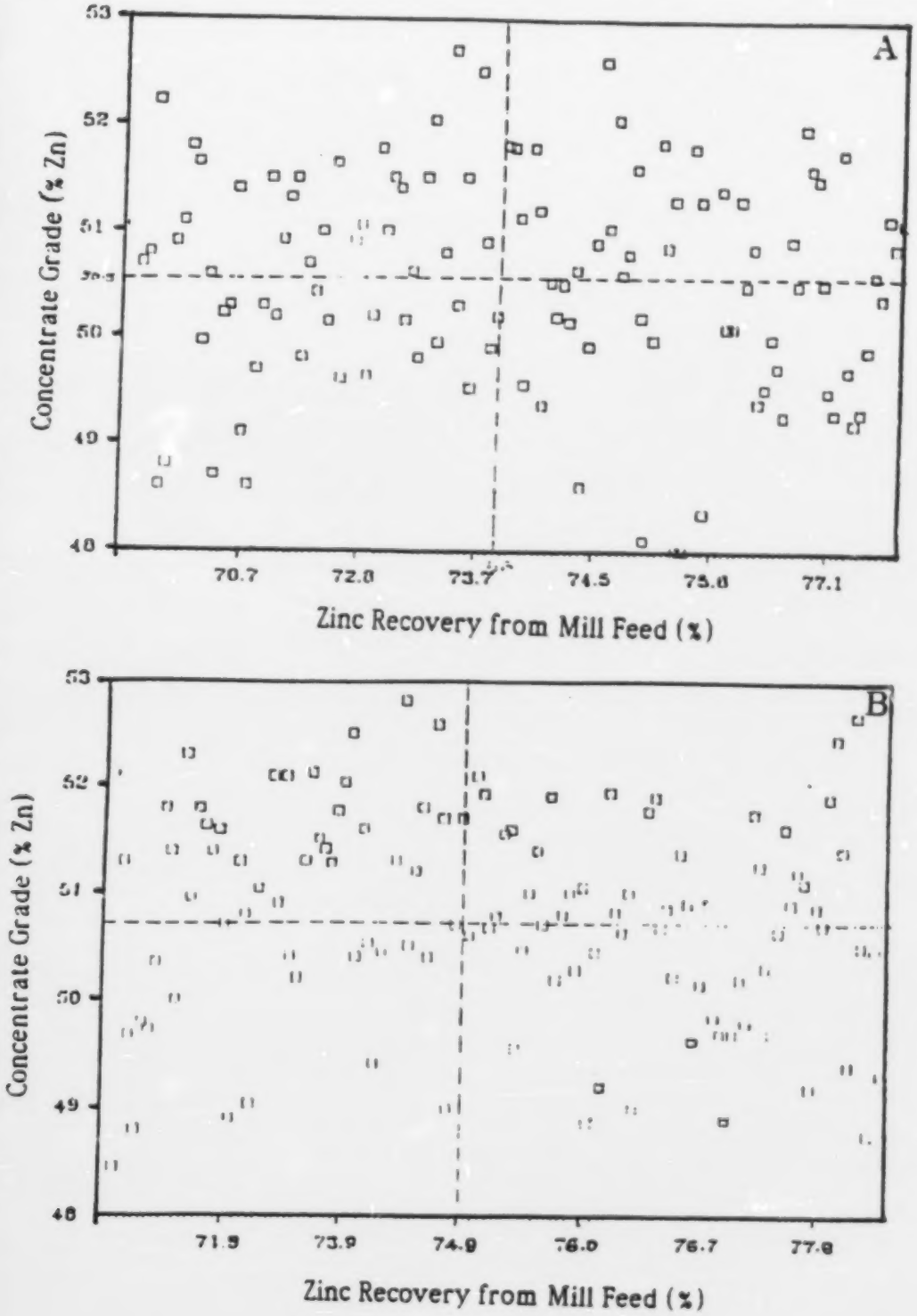


Figure 2 Zinc grade-recovery plots

A. Data with feed grade < 9.0% Zn

B. Data with feed grade > 9.0% Zn

1.2 SELECTION OF COMPOSITE SAMPLES

To determine causes of the circuit performance variability shown in Figure 1 a set of six composite samples was identified for close examination, each composite consisting of 6 to 9 daily samples. The location on the grade/recovery plot of these six composites is shown in Figure 3(a).

Table 2 summarizes the average circuit performance of each composite. Periods of good, average and poor performance were selected, mostly omitting extreme results. Tables A1 and A2 in the appendix give the dates from which the composites were prepared and the detailed metallurgy of each composite.

Composites were made for all L1/L2 daily samples that were retained during the October to May period: flotation feed, zinc circuit feed, zinc concentrate, and zinc circuit tailings.

1.3 ASSAYS ON ZINC CONCENTRATE COMPOSITES

Actual assays of the zinc concentrate composite samples varied significantly from the average of the daily assays (taken from daily metallurgical balances) for the composites. Figure 3(a) is zinc circuit grade-recovery based on the average of the daily assays of each composite. Using the actual assays obtained from the composites (after applying a data adjustment routine) yields the data in Figure 3(b) and Table 3. Table 4 compares the two sets of zinc assays for the six concentrates.

The difference in zinc assay increases with decreasing zinc content and is significant for all samples except that of composite 2 (52.5% Zn). The reason for this discrepancy is not immediately clear; however, it does shift somewhat the grade-recovery relationship of the composites (Figure 3). It is clear that composite 2 (separation efficiency[1] S.E. - 44.2%) is 'good' performance, composites 5 and 6 (S.E. - 34.0 and 35.5%) are 'poor' performance, and composites 1, 3, and 4 (S.E. -37.2 to 39.7%) are 'average' performance.

---

1 Separation efficiency is defined here as (Zn rec'y) x (Zn conc. grade) / 100

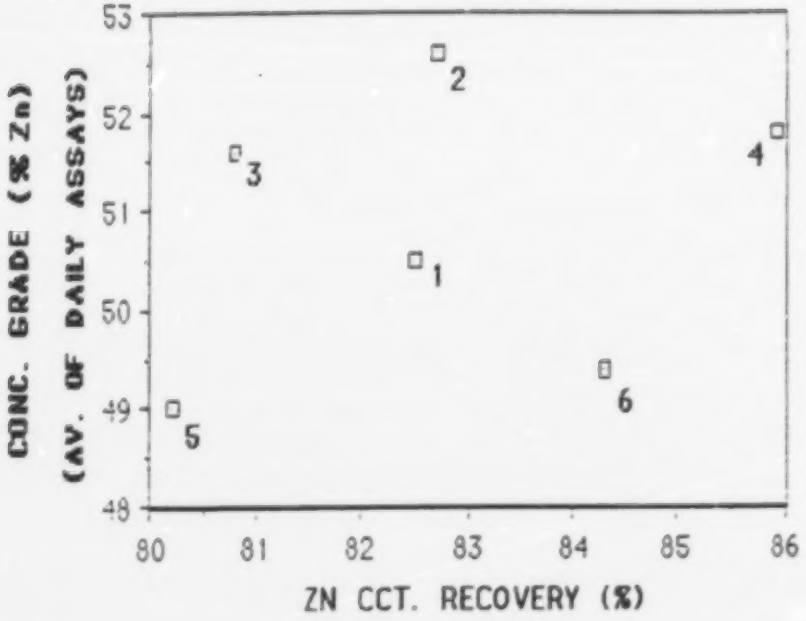


Figure 3(a). Zinc grade-recovery for the six composites using the average of the daily assays (obtained from daily metallurgical balances).

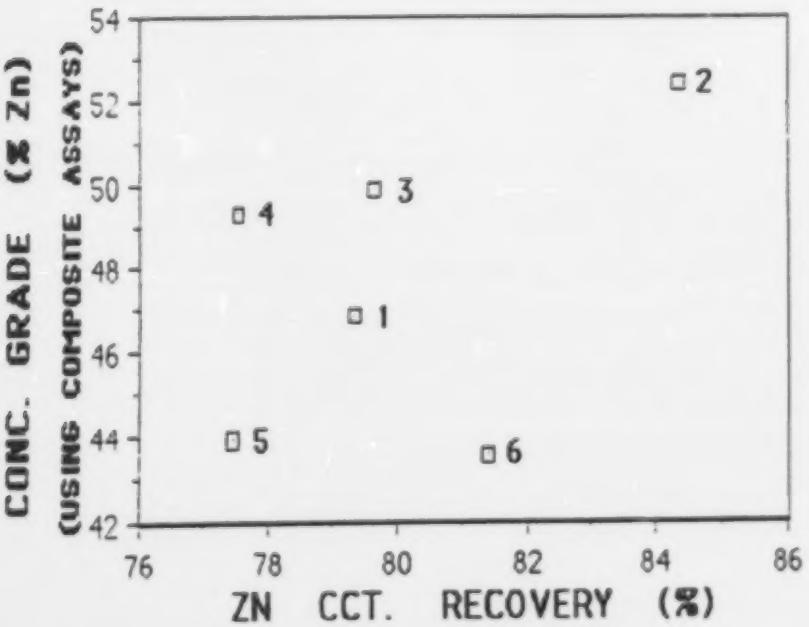


Figure 3(b). Zinc grade-recovery for the six composites using the actual assay of the composite samples (data adjustment has been applied).

Table 3 Performance summary of composites based on actual assays of the composite samples

COMPOSITE NUMBER	CIRCUIT FEED (%) GRADE		CONCENTRATE GRADE (%)			RECOVERY TO CONC (%)				SEP. EFF. (c*R)
	Zn	Pb	Zn	Pb	FeS2	WT.	Zn	Pb	FeS2	Zn
1	7.25	1	46.86	1.51	16.36	12.28	79.36	18.53	3.43	37.19
2	9.47	1.14	52.42	1.3	10.45	15.23	84.33	17.46	2.82	44.21
3	8.04	1.15	49.87	1.3	14.68	12.84	79.64	14.44	3.25	39.72
4	7.26	0.96	49.35	1.09	16.26	11.41	77.55	13.03	3.17	38.27
5	7.17	0.99	43.94	1.29	21.73	12.64	77.47	16.46	4.58	34.04
6	7.37	0.95	43.58	1.34	20.00	13.76	81.37	19.52	4.87	35.46

Table 4 Zinc assays of concentrates from the six composites

COMPOSITE NUMBER	CONCENTRATE GRADE (% Zn) AVERAGE OF DAILY COMPOSITE	COMPOSITE SAMPLE ASSAY	DIFFERENCE (%)
2	52.60	52.42	0.18
3	51.60	49.87	1.73
4	51.80	49.35	2.45
1	50.50	46.86	3.64
5	49.00	43.94	5.06
6	49.40	43.58	5.82

1.4 ANALYSIS AND EXAMINATION OF COMPOSITES

1.4.1 Lead Assay of Zinc Circuit Feed

Consider the Pb assays of the zinc circuit feed (Table 3) and the Pb separation performance around the Pb circuit (Table 5). There is insignificant difference in Pb levels in the zinc circuit feed as well as Pb circuit performance for the composite samples. While poor Pb circuit performance is often a distinct problem in operation of the zinc circuit, it does not appear in the analysis of these six composites.

1.4.2 Zinc Assay of Zinc Circuit Feed

Feed grade to the zinc circuit varied from 7.2% to 9.5% Zn and appreciably affected circuit performance (especially for composite 2); separation efficiency is plotted against zinc circuit feed grade in Figure 4. The very good performance of composite 2 can be attributed to the higher Zn assay of zinc circuit feed during that period.

Since the ore feed grade did not vary between composites nearly to the same extent (8.6 to 9.4% Zn, Table 1) the variation in feed to the zinc circuit cannot be explained, because it is not evident from the averages of the daily metallurgical balances for the composites that there is a significant difference in lead circuit performance (Table 5).

1.4.3 Pyrrhotite Content of Zinc Concentrate

The Frantz Isodyamic Magnetic Separator was used to assess the occurrence of pyrrhotite in zinc concentrates. Sized samples (between 20 and 44 μm) from each zinc concentrate composite were treated on the Frantz. No presence of pyrrhotite was detected.

1.4.4 Zn:Fe Ratio of Sphalerite

Concentrate and tailings samples from the six composites were prepared for SEM analysis (analysis performed by staff in the Department of Geology, University of Toronto) to determine if there existed a variation in the Zn:Fe ratio of the sphalerite; SEM results are summarized in Table 6. There is little variability in Zn:Fe in the concentrate samples (standard deviation of 0.4% Fe) and the average value (6.1 wt% Fe) is consistent with previous analysis performed by others.

Sphalerite in the tailings gave an average of 5.7% Fe with a standard

Table 5 Pb circuit performance of composite samples (based on average of daily metallurgical balances)

COMPOSITE NUMBER	RECOVERY to Pb CONCENTRATE Zn	Pb
1	10.6	69.2
2	10.4	74.6
3	10.9	69.5
4	9.6	76.2
5	10.2	71.9
6	9.7	72.8

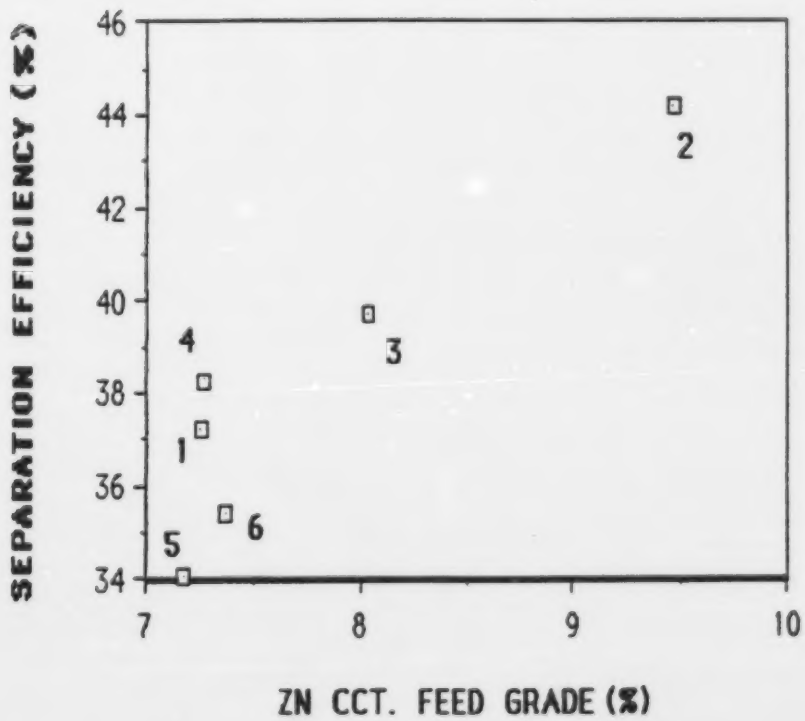


Figure 4 Zinc circuit separation efficiency versus zinc content of zinc circuit feed.

Table 6 SEM analysis for Zn:Fe ratio of sphalerite in composite samples

COMPOSITE NUMBER	Zn:Fe ATOMIC RATIO	WT% Fe in SPHALERITE
A. Concentrate		
1	10.7	5.7
2	8.7	6.9
3	9.6	6.3
4	10.1	6.0
5	10.1	6.0
6	10.3	5.9
Average		6.1
Standard Deviation		0.4
B. Tailings		
1	12.6	4.9
2	8.1	7.3
3	11.2	5.5
4	13.5	4.6
5	9.6	6.3
6	NA	NA
Average		5.7
Standard Deviation		1.1

deviation, from five composites, of 1.1% Fe (the standard deviation was higher because of the difficulty in finding many sphalerite particles in the tailings samples). Thus, there is no evidence of a significant difference in Fe content of sphalerite between that recovered to the concentrate and that reporting to the tailings.

1.4.5 Size Distribution of Zinc Circuit Feed

The particle size distribution of zinc circuit feed (Table 7) varied between composites and did show an effect upon circuit performance. In Figure 5 separation efficiency is plotted against % +400 mesh in zinc circuit feed; a reasonable relationship is evident (assuming that the data for composite 2 does not fit because of its considerably higher feed grade).

Table 7 Particle size distribution of zinc circuit feed

COMPOSITE NUMBER	PERFORMANCE	MILL FEED		Zn CCT. FEED			Zn CONC.	
		400 MESH	Minus Cycl. # 5	400 MESH	Minus Cycl. # 5	SEPARATION EFFICIENCY	400 MESH	Minus Cycl. # 5
		(%)		(%)			(%)	
5	Poor	38.3	22.8	39.9	21.7	34.0	7.7	39.2
6	Poor	36.0	25.4	36.7	25.1	35.5	8.2	40.5
1	Average	34.8	23.3	31.7	31.4	37.2	6.8	43.3
3	Average	33.8	24.1	31.5	27.0	39.7	5.1	46.5
4	Average	35.0	23.4	36.1	26.0	38.3	5.8	42.1
2	Good	34.0	23.4	31.9	27.3	44.2	6.4	45.0

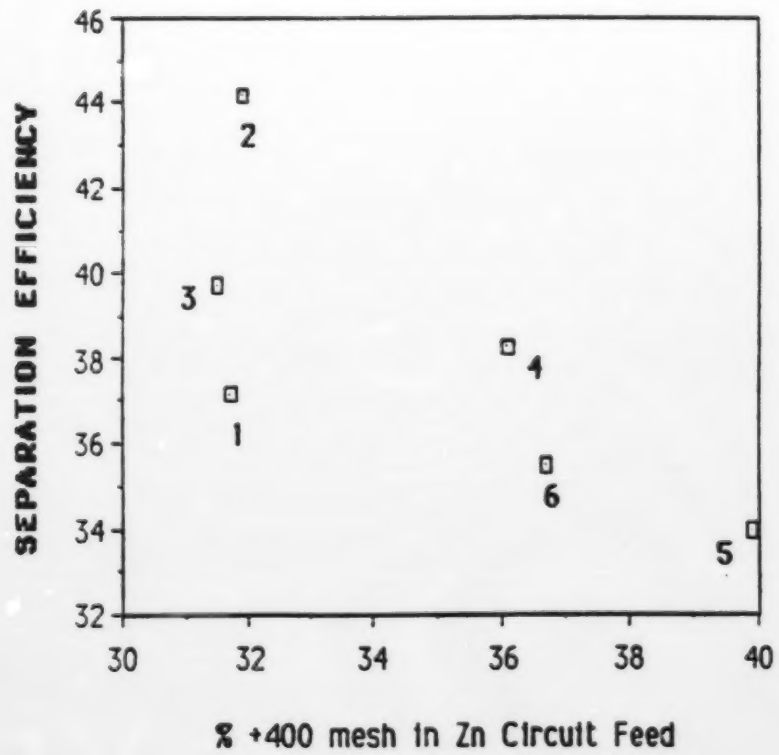


Figure 5 Zinc circuit separation efficiency versus particle size (%+400 mesh) of zinc circuit feed.

1.5 CONCLUSIONS AND RECOMMENDATIONS REGARDING THE CAUSES OF VARIABILITY IN ZINC CONCENTRATE QUALITY

CONCLUSIONS

- The scatter in the grade-recovery plot of Figure 3(b) is due to:
  (1) varying zinc circuit feed grade; composite 2 has better performance for this reason, and
  (2) varying grind; composites 5 and 6 have poor performance for this reason.

- Zn:Fe ratio of the sphalerite was similar in all composites.

- Pyrrhotite did not occur in the zinc concentrate.

- Pb assay of the zinc circuit feed was not identified as contributing to the variability in the performance of the composites.

RECOMMENDATIONS

- The variation in assays (between average of daily values and actual assay on the composite) is troubling and should be further evaluated for cause.

- The effect of Pb content of zinc circuit feed upon zinc circuit performance was not established in this test work because the Pb content did not vary significantly between the six composites. It is known that Pb has a detrimental effect upon zinc circuit performance at Brunswick; this aspect of zinc flotation deserves further study.

2. PART II - EVALUATING THE RELATIVE CONTRIBUTIONS TOWARD PYRITE RECOVERY IN THE ZINC CIRCUIT

Part II of the project employed a unique approach for assessing the relative contributions to pyrite flotation made by the three mechanisms:
(a) entrainment, (b) flotation, and (c) incomplete pyrite-sphalerite liberation. The purpose of this work was to provide a basis upon which further circuit improvements can be made, by clearly identifying the primary modes of pyrite recovery to the zinc concentrate.

The approach was to operate a pilot flotation column in parallel with the 2nd zinc cleaner. When operated correctly, the column eliminates recovery by the entrainment mode. Thus, the difference between pyrite recovery in the plant cleaner and the pyrite recovery in the column (at similar zinc recoveries) can be attributed largely to entrainment. Then, the presence of liberated pyrite in the column concentrate (as measured from a liberation assessment) can be assumed to be a result of flotation (mechanism (b)).

2.1 COLUMN FLOTATION OF 2nd CLEANER FEED

Column flotation experiments were conducted in July 1988 at B.M.S. using a portable 3.8 cm diameter x 6 m high column. The focus of the experiments was on zinc 2nd cleaner from line L1/L2 (problems in obtaining plant samples precluded comparative tests on the 1st and 3rd cleaners). Feed to the column was pumped continuously from the 2nd cleaner feed box using double stage peristaltic pumping; thus, column tests were performed over a long period (implying steady state conditions). The plant cleaner stage was sampled simultaneous to the column tests.

Results of the column and plant tests on the 2nd cleaner are summarized in Table 8. Three column tests are reported, as are the results from four plant surveys, including the data obtained on the 2nd cleaner by C. Bazin (March 31/88 internal BMS report, 'Initial investigation of L1/L2 zinc cleaners operation'). Figure 6 is the plot of pyrite recovery versus sphalerite recovery.

Plant tests P1 and P3 gave similar results; therefore, their products were combined for subsequent size analysis and assaying. Size-by-size data from the plant surveys and the column tests are given in appendix Tables A3 and A4.

Table 8 Flotation column and plant survey results on zinc 2nd cleaner

EST #	FEED ASSAY (%)				CONC. ASSAY (%)				REC'Y TO CONC. (%)			
	Zn	FeS2	Pb	Cu	Zn	FeS2	Pb	Cu	WT.	Zn	FeS2	Pb
COLUMN FLOTATION												
C1	38.91	31.1	3.3	0.35	51.8	11.4	2.4	0.36	56.3	75.0	20.8	41.5
C3	43.47	25.1	2.9	0.33	53.8	10.7	1.6	0.22	50.3	62.2	21.5	27.5
C4	37.67	33.5	3.6	0.37	51.2	13.3	1.8	0.28	49.4	67.1	19.7	25.1
PLANT FLOTATION												
P1	42.5	24.3	3.5	.38	46.1	17.2	3.3	.39	85.9	93.2	59.1	79.2
P2	41.1	27.3	2.8	.35	49.8	14.7	2.0	.32	68.0	82.4	36.9	49.0
P3	42.6	24.2	1.7	.27	48.1	16.5	1.5	.26	83.6	94.4	57.5	76.2
PB*	39.8	25.2	1.4	.40	46.9	15.8	1.2	.34	55.8	66.0	35.0	47.0

PB* DATA FROM C. BAZIN TEST

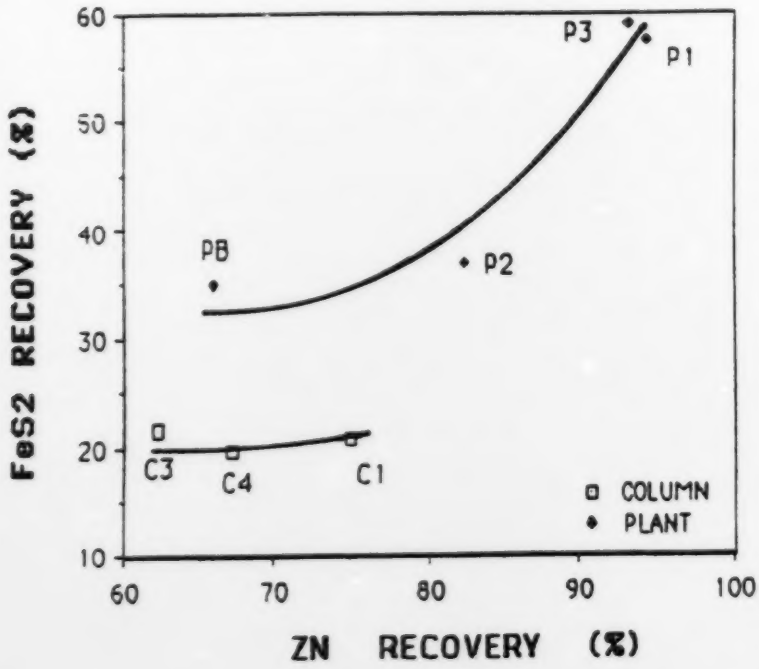


Figure 6. Pyrite recovery versus sphalerite recovery for the 2nd zinc cleaner, obtained from column tests and plant surveys. Column data is on a 3.8 cm diameter x 6 m high column.

2.1.1 Assessment of Pyrite Recovery by Entrainment

The column experiments were conducted such that recovery of feed water to the concentrate was negligible (<1%), and, therefore, entrainment recovery can be considered to have been negligible in the column tests. At a sphalerite recovery of 60 to 80%, pyrite recovery is about 20% in the column and 35% in the plant cells. The ratio of rate constants ($k_{sphalerite}/k_{pyrite}$) is about 3.1 for the plant cells and 5.0 for the column tests. Some of this difference is attributed to a refluxing action in the column that tends to improve separation, an improvement over and above that due to elimination of entrainment. However, it is apparent that entrainment accounts for a significant portion of the pyrite recovery in the plant 2nd cleaner; this is further addressed below.

Consider the data for a Zn recovery of 66% (pyrite recovery - 35% and solids weight recovery - 56%) in the plant 2nd cleaner (Test PB, Table 8 and Figure 6), and compare it to the average performance of column tests C1, C3 and C4 (Zn recovery - 68%, pyrite recovery - 21% and solids weight recovery - 52%). To mathematically account for entrainment, let

$$R' = R_f + (1 - R_f)R_e \qquad (1)$$

where R' is overall recovery of a given mineral, R_e is recovery due to entrainment, and R_f is recovery due to flotation (which includes both true flotation, mechanism(b), and flotation as a result of interlocking to a mineral species that is activated, mechanism (c)). Rearranging this equation yields

$$R_e = (R' - R_f)/(1 - R_f) \qquad (2)$$

For pyrite recovery in the plant 2nd cleaner R' - 35%. Assuming R_f - 21% (from the column experiment, where Zn recovery is approximately equal to Zn recovery in the plant 2nd cleaner), then R_e in the plant cells is given by

$$R_e = (0.35 - 0.21)/(1 - 0.21) = 0.18 \text{ (or } 18\%)$$

Another way to estimate the magnitude of recovery by entrainment is from the correlation presented by Trahar (Int. J. Min. Proc., 8, 1981), in which entrainment is directly related to water recovery R_w by

$$R_e = mR_w \qquad (3)$$

where the slope m is a function of particle size (increases for decreasing particle diameter). Trahar's correlations have recently been confirmed in experiments conducted in our laboratory. For 20μm sulfide particles m ~ 0.3. For the plant survey results reported by Bazin in all cases R_w is approximately equal to 90% of the solids weight recovery value. Thus, for the plant 2nd cleaner at a weight recovery of 56%, assume R_w - 50% and, therefore,

$$R_e - 0.3 \times 50\% - 15\%$$

The two approaches to estimating R_e agree closely (18% and 15%).

The ratio of pyrite recovery without entrainment to that with entrainment is R_f/R'. In the plant 2nd cleaner when Zn recovery is 66% (test P2), R_f/R' - 21/35, or 0.60, i.e. a contribution from entrainment of 40% (1-0.60) to the overall pyrite recovery.

For sphalerite R_f is estimated by

$$\begin{aligned} R_f &- (R' - R_e)/(1 - R_e) \\ &- (.66-.15)/(1-.15) \\ &- 0.60 \text{ (or 60\%)} \end{aligned}$$

Therefore, R_f/R' for sphalerite is given by 60/66, or 0.91, i.e. a contribution from entrainment of 9% (1-0.91) to the overall sphalerite recovery.

In plant surveys P1 and P3 (more representative of typical plant operation) Zn recovery is 94%, pyrite recovery is 58%, weight recovery is 85%, water recovery is approximately 76% (0.9 x 85%) and, therefore, R_e ~ 23% (0.3 x 76%). From equation (1)

$$R_{f(\text{pyrite})} - (0.58 - 0.23)/(1 - 0.23) - 0.45 \text{ (or 45\%)}$$

and

$$R_{f(\text{sphalerite})} - (0.94 - 0.23)/(1 - 0.23) - 0.92 \text{ (or 92\%)}$$

This is the pyrite recovery (45% compared to the actual 58%) that would be expected if mineral recovery by entrainment were somehow eliminated, i.e. a contribution from entrainment of 22% to the overall pyrite recovery in the

2nd cleaning stage. At the same time, for sphalerite there would be a contribution from entrainment of 2% to the overall sphalerite recovery.

2.1.2 Assessment of Pyrite Recovery by Flotation and Incomplete Liberation

Samples of column and plant 2nd cleaner concentrates were prepared for mineralogical examination. From two size fractions (+38µm and 20-38µm) an estimation of pyrite liberation was made by point counting, with a correction for stereological effects. The results are summarized in Table 9. The level of pyrite liberation is surprisingly high, and suggests that a significant portion of the pyrite recovered was via true flotation. It should be kept in mind that the Zn recovery obtained in the tests that these samples were drawn from was only about 67%; typical Zn recovery in one stage is closer to about 90%. Therefore, under typical conditions there will be considerably more pyrite recovered to the concentrate via locking to sphalerite than is indicated in Table 9.

From these results, it is estimated that for the 2nd zinc cleaner at typical conditions the pyrite particles recovered by nonentrainment mechanisms are accounted for as follows: 40 to 50% by flotation, 50 to 60% by incomplete liberation.

(Tests that were also conducted using the Frantz Isodynamic separator were inconclusive, because a sufficiently sharp separation between sphalerite and pyrite could not be attained at the particle sizes under consideration.)

Table 9 Summary of liberation analysis on column and plant concentrates

SAMPLE	# FREE PARTICLES		BINARY		% LIBERATION	
	FeS_2	(Zn,Fe)S	#	% FeS_2	FeS_2	(Zn,Fe)S
A. 20 to 38 µm fraction						
Column conc	62	546	77	19	76	86
Plant conc (P2)	87	484	36	36	84	94
B. +38 µm fraction						
Column conc	40	410	21	31	83	96
Plant conc (P2)	77	393	10	29	95	98

2.4 CONCLUSIONS AND RECOMMENDATIONS REGARDING THE CONTRIBUTIONS TOWARD PYRITE RECOVERY IN THE ZINC CIRCUIT

CONCLUSIONS

- A unique approach to assessment of the relative contributions of entrainment, flotation and incomplete liberation toward gangue recovery in mechanical flotation cells has been demonstrated.

The immediate conclusions are as follows:

- (i) Entrainment accounts for about 22% of the pyrite recovered in the 2nd zinc cleaner under typical operating conditions; at lower zinc recovery the contribution of entrainment to the overall pyrite recovery is as much as 40%.
  (ii) Entrainment accounts for about 2% of the sphalerite recovered in the 2nd zinc cleaner under typical operating conditions.

- For the balance of the pyrite recovery in the 2nd cleaning stage a significant proportion (40 to 50%) is accounted for by flotation (the rest is contributed by incomplete liberation).

RECOMMENDATIONS

- The conclusions have been derived from one set of experiments. Further experiments of this type should be conducted to verify the results, especially with respect to the distribution of pyrite between that reporting via flotation and that reporting via incomplete liberation.

- Column flotation (as a circuit of columns only or columns plus mechanical cells) should be investigated for zinc flotation. A cleaning circuit that employs column flotation has the potential to reduce pyrite recovery to the final concentrate by 20 to 40 %.

TABLE A1

Make-up of Composite Samples

COMPOSITE NO. 1	COMPOSITE NO. 2	COMPOSITE NO. 3
Date	Date	Date
OCT-06-86	OCT-23-86	DEC-14-86
OCT-25-86	MAR-03-87	MAR-16-87
OCT-28-86	MAR-30-87	APR-09-87
NOV-07-86	APR-01-87	MAY-05-87
NOV-08-86	APR-03-87	MAY-07-87
APR-28-87		MAY-11-87
APR-29-87		MAY-12-87

COMPOSITE NO. 4	COMPOSITE NO. 5	COMPOSITE NO. 6
Date	Date	Date
OCT-19-86	DEC-01-86	NOV-27-86
OCT-21-86	FEB-14-87	DEC-02-86
NOV-16-86	MAR-09-87	DEC-19-86
JAN-26-87		DEC-26-86
MAR-21-87		APR-14-87
MAR-28-87		
APR-07-87		

TABLE A2

DETAILS OF CIRCUIT PERFORMANCE FOR EACH COMPOSITE

COMPOSITE NO. 1 ZINC ASSAYS DISTRIBUTIONS (L1/L2)

DATE	MILL FEED	L1/L2	L3	ZINC CONC	FINAL TAILS	FROM CIRCUIT FEED
OCT-06-86	8.7	50.5	50.5	74.1	16.2	82.1
OCT-25-86	9.6	50.4	48.5	74.3	14.8	83.4
OCT-28-86	10.1	50.5	51.3	74.1	13.7	84.4
NOV-07-86	8.2	50.5	49.7	74.1	14.3	83.8
NOV-08-86	8.6	50.6	46.9	73.2	18.1	80.2
APR-28-87	9.0	50.6	49.6	74.2	17.2	81.2
APR-29-87	9.4	50.5	51.0	74.5	15.8	82.5
AVERAGE :	9.1	50.5	49.6	74.1	15.7	82.5
STD (S) :	0.6	0.1	1.4	0.4	1.5	1.4
R. STD (V) :	0.067	0.001	0.029	0.005	0.093	0.017
COUNT :	7.0	7.0	7.0	7.0	7.0	7.0
MAX. VALUE :	10.1	50.6	51.3	74.5	18.1	84.4
MIN. VALUE :	8.2	50.4	46.9	73.2	13.7	80.2

COMPOSITE NO. 2 ZINC ASSAYS DISTRIBUTIONS (L1/L2)

DATE	MILL FEED	L1/L2	L3	ZINC CONC	FINAL TAILS	FROM CIRCUIT FEED
OCT-23-86	9.8	52.8	50.7	74.3	14.9	83.3
MAR-03-87	8.7	52.7	51.9	73.4	16.8	81.4
MAR-30-87	10.1	52.5	51.4	74.0	17.2	81.1
APR-01-87	9.7	52.6	51.2	74.7	13.3	84.9
APR-03-87	8.8	52.5	52.1	73.7	15.4	82.7
AVERAGE :	9.4	50.6	51.5	74.0	15.5	82.7
STD (S) :	0.6	0.1	0.6	0.5	1.6	1.5
R. STD (V) :	0.067	0.003	0.011	0.007	0.1	0.019
COUNT :	5.0	5.0	5.0	5.0	5.0	5.0
MAX. VALUE :	10.1	52.8	52.1	74.7	17.2	84.9
MIN. VALUE :	8.7	52.5	50.7	73.4	13.3	81.1

TABLE A2 (continued)

DETAILS OF CIRCUIT PERFORMANCE FOR EACH COMPOSITE

COMPOSITE NO. 3 ZINC ASSAYS DISTRIBUTIONS (L1/L2)

DATE	MILL FEED	L1/L2	L3	ZINC CONC	FINAL TAILS	FROM CIRCUIT FEED
DEC-14-86	8.0	51.6	49.9	72.5	15.6	82.3
MAR-16-87	9.8	51.6	51.1	71.5	16.8	81.0
APR-09-87	8.6	51.5	51.5	72.2	18.0	80.0
MAY-05-87	9.7	51.8	51.4	71.3	18.2	79.7
MAY-07-87	8.7	51.5	49.2	71.4	16.2	81.5
MAY-11-87	9.3	51.6	52.0	71.6	16.7	81.1
MAY-12-87	10.4	51.4	50.6	71.5	18.2	79.7
AVERAGE :	9.2	51.6	50.8	71.7	17.1	80.8
STD (S) :	0.8	0.1	1.0	.5	1.0	1.0
R. STD (V) :	0.090	0.002	0.019	0.006	0.061	0.012
COUNT :	7.0	7.0	7.0	7.0	7.0	7.0
MAX. VALUE :	10.4	51.8	52.0	72.5	18.2	82.3
MIN. VALUE :	8.0	51.4	49.2	71.3	15.6	79.7

COMPOSITE NO. 4 ZINC ASSAYS DISTRIBUTIONS (L1/L2)

DATE	MILL FEED	L1/L2	L3	ZINC CONC	FINAL TAILS	FROM CIRCUIT FEED
OCT-19-86	9.8	51.4	51.3	76.5	11.4	87.0
OCT-21-86	9.6	51.8	48.0	76.4	9.9	88.5
NOV-16-86	9.6	51.9	50.0	76.5	11.9	86.5
JAN-26-87	8.4	51.6	52.0	76.8	15.9	82.8
MAR-21-87	9.9	51.8	50.3	77.2	11.5	87.0
MAR-28-87	9.6	52.0	52.3	76.8	13.9	84.7
APR-07-87	8.7	51.8	52.3	77.2	14.1	84.6
AVERAGE :	9.2	51.8	50.9	76.8	12.7	85.8
STD (S) :	0.6	0.2	1.6	0.3	2.1	1.9
R. STD (V) :	0.069	0.004	0.031	0.004	.162	0.022
COUNT :	7.0	7.0	7.0	7.0	7.0	7.0
MAX. VALUE :	9.9	52.0	52.3	77.2	15.9	88.5
MIN. VALUE :	8.4	51.4	48.0	76.4	9.9	82.8

TABLE A2 (continued)

DETAILS OF CIRCUIT PERFORMANCE FOR EACH COMPOSITE

COMPOSITE NO. 5 ZINC ASSAYS DISTRIBUTIONS (L1/L2)

DATE	MILL FEED	L1/L2	L3	ZINC CONC	FINAL TAILS	FROM CIRCUIT FEED
DEC-01-86	9.0	49.0	47.5	72.6	16.0	81.9
FEB-14-87	8.6	49.1	51.7	70.7	19.4	78.5
MAR-09-87	8.2	48.9	50.3	72.7	18.1	80.1
AVERAGE :	8.6	49.0	49.8	72.0	17.8	80.2
STD (S) :	0.4	0.1	2.1	1.1	1.7	1.7
R. STD (V) :	0.046	0.002	0.043	0.016	0.096	0.021
COUNT :	3.0	3.0	3.0	3.0	3.0	3.0
MAX. VALUE :	9.0	49.1	51.7	72.7	19.4	81.9
MIN. VALUE :	8.2	48.9	47.5	70.7	16.0	78.5

COMPOSITE NO. 6 ZINC ASSAYS DISTRIBUTIONS (L1/L2)

DATE	MILL FEED	L1/L2	L3	ZINC CONC	FINAL TAILS	FROM CIRCUIT FEED
NOV-27-86	8.8	49.5	50.9	76.2	15.0	83.6
DEC-02-86	9.5	49.8	50.0	76.1	13.8	84.6
DEC-19-86	8.4	49.3	51.1	76.4	12.9	85.6
DEC-26-86	8.1	49.4	50.7	76.0	16.0	82.6
APR-14-87	9.2	49.2	50.4	76.1	13.3	85.1
AVERAGE :	8.8	49.4	50.6	76.2	14.2	84.3
STD (S) :	0.6	0.2	0.4	0.2	1.3	1.2
R. STD (V) :	0.065	0.005	0.009	0.002	0.090	0.014
COUNT :	5.0	5.0	5.0	5.0	5.0	5.0
MAX. VALUE :	9.5	49.8	51.1	76.4	16.0	85.6
MIN. VALUE :	8.1	49.2	50.0	76.0	12.9	82.6

TABLE A3

SIZE-BY-SIZE RESULTS OF PLANT AND COLUMN TESTING

A. PLANT SECOND CLEANER DATA

Test No.: P1 and P3 combined
Sample: Plant Feed

Size Fraction	Effective Particle Sep. Size (um)	ADJUSTED ASSAYS (%) PbS	CuFeS2	(Zn,Fe)S	FeS2	DISTRIBUTION (%) PbS	CuFeS2	(Zn,Fe)S	FeS2
+ 400	+38	2.9	0.9	68.0	27.0	14	15	14	15
- 400	-38	2.9	0.8	72.0	25.4	86	85	86	85
Cyclo #1&2	25	2.7	0.7	56.4	43.9	5	4	4	8
Cyclo #3	18	1.8	0.6	66.5	34.1	9	11	14	19
Cyclo #4&5	10	2.2	0.6	71.5	26.9	21	19	28	29
Minus 5	-10	3.9	1.1	76.7	18.7	51	51	41	28
Feed (*)		2.9	0.8	71.5	25.6	100	100	100	100

Test No.: P-2
Sample: Plant Feed

Size Fraction									
+ 400	+38	3.2	0.9	64.7	28.5	27	27	29	30
- 400	-38	3.6	1.0	67.1	27.8	73	73	71	70
Cyclo #1&2	25	3.5	0.9	51.5	51.1	3	2	2	5
Cyclo #3	18	2.3	0.8	61.7	38.9	7	8	9	14
Cyclo #4&5	10	2.7	0.8	67.6	31.0	18	20	24	26
Minus 5	-10	4.6	1.3	69.6	20.5	45	42	36	25
Feed (*)		3.5	1.0	66.4	28.0	100	100	100	100

Test No.: P1 and P3 combined
Sample: Plant Conc

Size Fraction									
+ 400	+38	2.4	0.9	74.2	21.5	14	15	14	15
- 400	-38	2.5	0.8	77.2	20.5	86	85	86	85
Cyclo #1&2	25	1.9	0.7	68.6	31.3	4	4	4	7
Cyclo #3	18	1.4	0.6	75.6	24.7	8	10	14	17
Cyclo #4&5	10	1.7	0.5	78.1	20.4	19	19	28	27
Minus 5	-10	3.6	1.1	78.5	17.7	55	52	39	33
Feed (*)		2.5	0.8	76.8	20.6	100	100	100	100

TABLE A3 (continued)

SIZE-BY-SIZE RESULTS OF PLANT AND COLUMN TESTING

Test No.: P2
Sample: Plant Conc

Size Fraction	Effective Particle Sep. Size (um)	ADJUSTED ASSAYS (%) PbS	CuFeS2	(Zn,Fe)S	FeS2	DISTRIBUTION (%) PbS	CuFeS2	(Zn,Fe)S	FeS2
+ 400	+38	2.3	1.0	81.0	16.9	18	17	18	19
- 400	-38	2.3	1.0	82.3	16.0	82	83	82	81
Cyclo #1&2	25	1.5	0.7	67.4	32.6	1	1	1	3
Cyclo #3	18	1.2	0.7	76.0	21.7	5	7	9	13
Cyclo #4&5	10	1.3	0.7	81.6	17.3	15	17	26	28
Minus 5	-10	3.2	1.3	84.7	13.4	61	58	45	36
Feed (*)		2.3	1.0	82.1	16.2	100	100	100	100

Test No.: P1 and P3 combined
Sample: Plant Tails

Size Fraction									
+ 400	+38	5.2	0.9	35.0	56.5	21	23	25	21
- 400	-38	6.0	0.9	32.1	63.0	79	77	75	79
Cyclo #1&2	25	4.9	0.8	25.0	76.1	5	5	5	7
Cyclo #3	18	3.6	0.7	31.5	70.4	10	12	16	19
Cyclo #4&5	10	5.1	0.6	30.2	67.4	22	17	24	28
Minus 5	-10	8.6	1.4	35.6	52.0	42	42	31	24
Feed (*)		5.8	0.9	32.8	61.5	100	100	100	100

Test No.: P2
Sample: Plant Tails

Size Fraction									
+ 400	+38	4.9	1.1	40.4	52.2	25	27	29	27
- 400	-38	5.5	1.2	38.5	55.0	75	73	71	73
Cyclo #1&2	25	4.4	0.9	28.1	75.9	4	4	3	6
Cyclo #3	18	2.9	0.8	35.9	65.2	8	10	13	18
Cyclo #4&5	10	4.2	0.7	36.1	62.9	20	17	23	29
Minus 5	-10	8.4	1.8	44.0	39.4	43	43	31	20
Feed		5.3	1.1	39.0	54.2	100	100	100	100

TABLE A3 (continued)

SIZE-BY-SIZE RESULTS OF PLANT AND COLUMN TESTING

B. COLUMN DATA

Test No.: C1, C3 and C4 combined
Sample: Column Conc

Size Fraction	Effective Particle Sep. Size (um)	Assays (%) PbS	CuFeS2	(Zn,Fe)S	FeS2	DISTRIBUTION (%) PbS	CuFeS2	(Zn,Fe)S	FeS2
+ 400	+38	1.8	0.9	82.5	15.9	11	12	12	15
- 400	-38	2.2	0.9	85.9	13.0	89	88	88	85
Cyclo #1&2	25	1.7	0.8	77.4	21.2	4	5	5	9
Cyclo #3	18	1.4	0.8	82.0	17.9	9	12	14	19
Cyclo #4&5	10	1.4	0.8	86.2	13.6	18	23	28	28
Minus 5	-10	3.2	1.1	88.2	9.8	59	49	41	29
Feed (*)		2.2	0.9	85.5	13.4	100	100	100	100

Test No.: C1, C3 and C4 combined
Sample: Column Tails

Size Fraction									
+ 400	+38	5.2	1.3	39.3	53.8	25	26	24	26
- 400	-38	5.3	1.3	43.4	51.3	75	74	76	74
Cyclo #1&2	25	4.6	1.2	37.4	63.3	5	5	5	7
Cyclo #3	18	3.1	0.9	33.2	67.9	6	7	8	13
Cyclo #4&5	10	4.2	0.9	39.8	60.0	19	17	22	28
Minus 5	-10	6.8	1.6	49.9	38.7	45	44	41	26
Feed (*)		5.2	1.3	42.3	51.9	100	100	100	100

(*) Backcalculated values

TABLE A4

SIZE-BY-SIZE RECOVERIES FOR PLANT AND COLUMN TESTS

A. PLANT SECOND CLEANER DATA

Test No.: P1 and P3 combined

Size Fraction	Effective Part. Sep Size (um)	RECOVERY TO CONC (Using adjusted assays) PbS	CuFeS2	(Zn,Fe)S	FeS2
+ 400	+38	71	83	92	67
- 400	-38	76	87	95	71
Cyclo #1 & 2	25	49	69	88	51
Cyclo #3	18	60	76	90	57
Cyclo #4 & 5	10	68	84	94	65
Minus 5	-10	89	95	98	90
Feed		76	86	94	71

Test No.: P2

+ 400	+38	43	63	75	36
- 400	-38	41	64	80	38
Cyclo #1 & 2	25	26	46	78	38
Cyclo #3	18	32	53	79	36
Cyclo #4 & 5	10	33	54	84	39
Minus 5	-10	43	67	76	41
Feed		42	64	79	37

B. COLUMN DATA

Test No.: C1, C3 and C4 combined

Size Fraction	Effective Part. Sep. Size (um)	RECOVERY TO CONC PbS	CuFeS2	(Zn,Fe)S	FeS2
+ 400	+38	15	25	51	13
- 400	-38	33	46	70	23
Cyclo #1 & 2	25	25	39	65	23
Cyclo #3	18	38	54	78	27
Cyclo #4 & 5	10	28	49	72	21
Minus 5	-10	35	44	67	22
Feed		29	42	67	20